EXPERIMENTAL AND THEORETICAL STUDIES OF ICE-ALBEDO FEEDBACK PROCESSES IN THE ARCTIC BASIN

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LONG TERM GOALS

Our overall objective is to develop a quantitative understanding of the processes which collectively make up the *ice-albedo feedback mechanism*. This mechanism is generally believed to be a major factor in amplifying variations that occur within the earth's climate system. To achieve this understanding, we must first learn how shortwave radiation is absorbed and distributed in the ice and upper ocean, then assess the effects of this distribution on the regional heat and mass balance of the ice pack. Complicating the problem are a variety of issues related to the extreme sub-grid scale variability of the arctic ice cover and to how such variability can be accounted for in large-scale climate and general circulation models.

OBJECTIVES

While we plan to investigate a wide variety of specific problems related to the interaction of shortwave radiation with the ice and ocean, there are three general questions that provide the focus for this study:

1. How is shortwave radiation that enters the ice-ocean system partitioned between reflection, surface melting, internal heat storage, and transmission to the ocean, and how is this partitioning affected by the physical properties of the ice, snow cover, melt ponds and distribution of particulates?
2. What is the areal distribution of ice, ponds and leads; how does this distribution vary with time; and how does it affect area-averaged heat and mass fluxes?
3. What are the crucial variables needed to characterize ice-albedo feedback processes and their effect on the heat and mass balance of the ice pack, and how accurately can they be treated through simplified models and parameterizations?

APPROACH

These issues will be addressed through a combination of field measurements, laboratory observations and theoretical modeling. Field data will be obtained during a 13 month period in

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1997-98 at the SHEBA (Surface HEat Budget of the Arctic Ocean) drift station in the Central Beaufort Sea. The work will be carried out jointly with investigators (D.K. Perovich, J.A. Richter-Menge, W.B. Tucker III and M. Sturm) from the U.S. Army Cold Regions Research and Engineering Laboratory in Hanover NH and Fairbanks AK. Activities this fall will involve selecting and surveying a primary floe, selecting measurement sites and deploying instrumentation. Continuously recording instrument packages will be deployed at several Time Series Measurement (TSM) sites (see Fig. 1) where ice temperature profiles, ice growth rates and snow depths will be monitored throughout the experiment. At least one of the TSM sites will be located on a refreezing melt pond to investigate long-term differences in the mass balance of ponded and unponded ice. Numerous hot wire thickness gauges will be installed at other sites on the floe, one important objective being to measure growth rates across one or more pressure ridge keels. Routine observations carried out during the winter will be aimed at quantities needed to estimate area-averaged heat and mass fluxes.

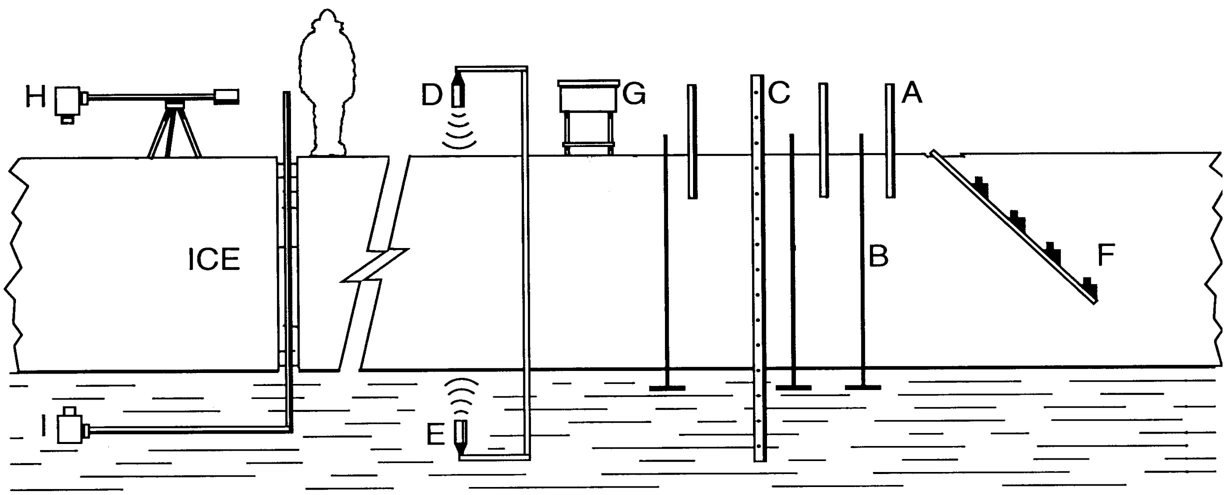

Figure 1. Layout of Time Series Measurement site (TSM). The TSM sites consist of (A) ablation stakes, (B) thickness gauges, (C) a thermistor string, (D) an above ice sonic sounder, (E) an underice sonic sounder, (F) irradiance detectors, and (G) a data logger. The sites will be visited periodically for measurements of spectral albedo (H) and transmittance (I) and snow and ice physical properties.

While we can predict with some confidence ice growth rates, salt fluxes to the ocean and heat exchange with the atmosphere during the freezing season for essentially any thermal forcing and any thickness of snow and undeformed ice, numerous uncertainties exist during the summer melt season and fall freeze-up when changes in ice conditions and optical properties are rapid and the impact of ice-albedo feedback processes are greatest. For this reason, much of our field work will be focused on these important periods. We expect to have 4-6 UW/CRREL investigators at the drift station from Spring through Fall 1998. The spring effort will be directed primarily towards obtaining detailed information on the state of the ice and snow cover at the onset of the melt season. Summer observations will be carried out on several different floe types where the focus will be on measuring the temporal evolution and spatial variability of such quantities as albedo, absorption and storage of solar energy by the ice, light transmission to the ocean, pond coverage and mass changes. Of concern is the possibility that soot and particulates generated by the ship may alter the albedo and melt cycle of the surrounding ice. We plan to survey particulate distribution within the region throughout the spring and summer. A model developed under another ONR grant (N0001490J1075) will be used to assess the impact of these particulates on radiative transfer and melting of ice within the experimental region.

Process-oriented modeling will be carried out to supplement and augment the field studies. Field data on ice structure and optical properties will be combined with laboratory data to develop and verify a model that relates structural and optical properties in warm sea ice. Such a model is needed to provide an accurate description of radiative transfer in sea ice and will form the basis for modeling efforts to predict the optical evolution of the ice cover during the summer melt season. A Monte Carlo model will be used in the analysis of the experimental data and to develop optical parameterizations that are suitable for use in our 4-stream radiative transfer model. Because *in situ* measurements of microstructure are impractical in warm ice, thin section data from ongoing laboratory studies will be used to characterize the structure of major ice types and consequent effects on radiative transfer.

An important objective of the program is to apply information obtained from local process and time evolution studies to the estimation of areally-integrated heat and mass fluxes. For this purpose, we plan to conduct surveys that will give us a statistical picture of the spatial variability within individual ice types and will provide quantitative information on the fractional area covered by these categories within the SHEBA region. Surface-based surveys will be conducted routinely during the spring and summer to sample albedo, snow and ice properties, melt pond depth and area, surface topography, particulate loading and lead temperatures. Helicopter surveys will be conducted throughout the summer to look at local and larger-scale variations in ice concentration, melt pond fraction, floe size distribution, floe perimeter and surface reflectivity. Such data will play an important part in obtaining regional estimates of shortwave input to the ocean, lateral melting on floe edges and melt pond effects. When combined with corresponding data from the atmosphere and ocean, this information should lead to a much more complete understanding of ice-albedo feedback processes in the Arctic.

ACCOMPLISHMENTS

Since the project began in May 1997, efforts have been focused primarily on planning, preparation and shipment of gear needed to carry out the field work at the SHEBA ice camp. Attention has now shifted to: (1) the design, construction and testing of specialized field equipment that will be used to sample the radiation field above and within the ice during the summer, and (2) the development and refinement of theoretical techniques needed for interpretation of SHEBA field data. Problems we are working on include: (1) ways to directly determine heat storage, light transmission and structural/optical changes within summer ice using Monte Carlo and multistream radiative transfer models, (2) an inverse method to infer vertical variations in the properties of warm ice using spectral data on reflection and transmission, (3) particulate sampling methods, and (4) a quantitative assessment of how the type and vertical distribution of particulates affect the radiation field within the ice.

We are continuing to develop a cylindrical, multilayer Monte Carlo model that should allow us to determine vertical variations in the optical properties of the ice from radiation data collected in vertical boreholes during SHEBA. In support of this work, we are designing and constructing custom radiation detectors that will improve our ability to measure incident and upwelling spectral irradiances above the ice, as well as the depth dependence of radiance and irradiance in the interior of the ice. The Monte Carlo model has been enhanced to include refraction at all horizontal and vertical boundaries, and to predict radiance distributions within the ice. It is now being used to evaluate the accuracy of various radiative transfer models that have been applied to sea ice. We are also working on extending our laboratory-based observations of temperature-induced changes in microstructure to include multiyear ice.

SCIENTIFIC/TECHNICAL RESULTS

Using the Monte Carlo model, we have been able to show that our four-stream radiative transfer model is able to predict spectral irradiances, albedos and transmissivities with an accuracy of about one percent for volume scattering asymmetry parameters of up to about 0.95. This means that the four-stream model should be able to accurately treat natural sea ice under most conditions found in nature. We have also been able to demonstrate that the radiative transfer inversion technique developed with SHEBA Phase I funding should allow us to obtain inherent optical properties of sea ice in cases which closely represent the structure of the summer ice we expect to encounter during SHEBA. We anticipate that this technique will make it possible for us to probe ice properties non-destructively with useful levels of accuracy beneath melt ponds and other summer ice types where direct sampling techniques (such as core extraction) would alter optical and other physical properties of the sample.

IMPACT FOR SCIENCE

Much of the data obtained during the field effort will be unique and will provide the means to test a variety of theoretical models dealing with: (1) the transmission and absorption of light by the ice pack, (2) the role of leads and melt ponds in the regional heat and mass balance, (3) the storage of solar heat in the water and its interaction with the ice cover, and (4) the seasonal evolution of the ice thickness distribution. Ultimately, we expect that this research will result in an improved understanding and treatment of ice-albedo feedback processes that can be used to enhance the accuracy of predictions made by large-scale climate and general circulation models.

RELATED PROJECTS

The work discussed above is part of a group proposal for research that will be carried out jointly with investigators (D. K. Perovich et al.) at CRREL under ONR Contract N00014-97-MP-30046. We also expect to work closely with SHEBA ocean investigators (Morison et al.; Paulson and Pegau) studying processes related to the recycling of solar energy absorbed by the ocean. In particular, we will be looking at how the state of the ice affects shortwave input to the water column, as well as at how this energy feeds back to alter ice concentration and thickness. Heat and mass balance data collected by this project will be used as input to modeling efforts funded under SCICEX and NASA-POLES (D.A. Rothrock et al.) that will calculate the ice thickness distribution within the SHEBA region throughout the experiment. Such information is needed in efforts to estimate regional fluxes from local observations. Achievement of the ultimate SHEBA objectives will require integration of the ice data with a wide variety of additional data on incident radiation, cloud conditions, turbulent heat fluxes, upper ocean conditions and remote sensing information. Accomplishing this integration will require close cooperation with numerous other SHEBA investigators funded by ONR and NSF.

PUBLICATIONS

Mobley, C, et al., Modeling light propagation in sea ice, IEEE TGRS (submitted)